Photographic identification of humpback and blue whales off the US West Coast: Results and updated abundance estimates from 2008 field season

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ABSTRACT

Photographic identification of humpback and blue whales was conducted along the US West Coast in 2008 for the primary purposes of generating updated abundance estimates of both species using mark-recapture. We conducted 66 days of dedicated and opportunistic photo-identification surveys off California, Oregon, and Washington primarily between June and November 2008. Additional photographic identifications were obtained by collaborating researchers and naturalists including those working from whale watch boats in areas like the Santa Barbara Channel and Monterey Bay. For all of the US West Coast, 808 identifications were made of 497 unique humpback whales which represented the largest number of individuals identified in any year of research so far along the US West Coast. A total of 437 identifications of 216 unique blue whales were made along the West Coast with almost half of these from the Santa Barbara Channel. Petersen mark-recapture estimates for humpback whales off California-Oregon yielded estimates for 2007-2008 of 2,043 (CV=0.10) humpback whales, the largest we have obtained to date consistent with an 8% annual rate of increase, although trends for the last 10 years have been more erratic largely due to our sample representing a decreasing proportion of this growing population leading to greater variation and possibly greater susceptibility to biasing factors. Estimates of humpback whales off Washington, a feeding aggregation relatively distinct from California-Oregon, were more variable but in the range of 500 animals. Blue whale photographic identifications from 2005 to 2008 were pooled to generate a single improved abundance estimated based on identifications from systematic surveys in 2005 and 2008 conducted by SWFSC as the unbiased sample and all other identifications as the 2nd independent sample. This pooled sample yielded an improved abundance estimate of 2,497 (versus the previous 2,842) with a tighter CV than had been possible previously. This estimate is slightly higher than the mark-recapture estimates of about 2,000 from the 1990s and may reflect a slight increase in blue whale abundance. These estimates are in contrast to the sharp decline in estimates of blue whales in this region from line-transect estimates since the 1990s. This discrepancy between the two methods appears to be the result of blue whales expanding their distribution since the 1990s and only being present part of the time off the US West Coast lowering the average density present (but not reflecting an actual population decline).

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INTRODUCTION

This report summarizes the results of photographic identification research conducted on blue and humpback whales off the US West Coast by Cascadia Research and collaborators in 2008 including comparisons to previous years. The primary objectives of this research is to obtain new estimates of humpback and blue whale abundance along the US west coast based on mark-recapture of photographically identified individuals and examine trends in abundance.

Starting in the early 1990s, photo-ID of humpback and blue whales along the US West Coast has provided accurate estimates of abundance using capture-recapture methods (Calambokidis et al. 1990a, 1990b, Calambokidis and Barlow 2004). These have complimented density-based abundance estimates available from line-transect surveys conducted by SWFSC (Barlow 2009, Barlow and Forney 2007, Forney 2007, Calambokidis and Barlow 2004). While annual estimates of humpback whales have been obtained from mark-recapture, blue whale abundance has only been primarily possible when at least one representative sample was obtained from the periodic surveys by SWFSC systematically covering both inshore and offshore waters (Calambokidis and Barlow 2004).

Humpback and blue whales are considered endangered and their populations were depleted by whaling throughout most of their range. Both species make seasonal migrations between low latitude areas in winter and high latitude areas in summer. Blue whales feed off California from May through November (Dohl *et al.* 1983) and migrate to waters off Mexico and Central America in winter and spring (Calambokidis *et al.* 1990b, Stafford *et al.* 1999, Mate *et al.* 1999, Chandler *et al.* 1999). Photographic identification of blue whales has revealed that animals identified off California are part of an eastern North Pacific population of blue whales that ranges as far north as the Queen Charlotte Islands and the Gulf of Alaska (Calambokidis et al. 2009) and as far south as the Costa Rica Dome (Chandler *et al.* 1999).

Recent studies of humpback whales in the entire North Pacific conducted under the SPLASH project have revealed a complex population structure with high degree of site fidelity to specific feeding and wintering areas but without a one-to-one association between these areas (Calambokidis et al. 2008). Overall abundance of humpback whales in the North Pacific was growing at 4-7% per year and through 2006 numbered about 20,000 (Calambokidis et al. 2008, Barlow et al. Submitted).

METHODS

In 2008 we sought to:

1. Obtain a large and representative sample of humpback and blue whale identifications from coastal waters and, where possible, offshore waters of the West Coast in 2008 to supplement that already available for past years. This included dedicated photo-effort, opportunistic identifications obtained as part of other research, and identifications provided opportunistically by collaborators.
2. Compare identification photographs obtained during the SWFSC systematic surveys conducted in 2005 and 2008 with those available from our other surveys.

3. Generate new abundance estimates of humpback and blue whales through 2008 using mark-recapture.
4. Compare these estimates with those obtained during the last 17 years to evaluate potential trends in abundance.

Survey effort

A major focus of our field effort was to obtain as large a sample of photographic identifications as possible with broad geographic and temporal coverage. Strategies for achieving this included: 1) conduct small boat operations in many different areas, 2) cover large areas both offshore and inshore, 3) effectively sample large concentrations of whales, and 4) achieve broad temporal coverage. We achieved these objectives with a combination of dedicated small boats surveys, opportunistic identifications during our other field research, and identifications from other opportunistic sources.

Cascadia conducted 66 days of dedicated and opportunistic photo-identification surveys off California, Oregon, and Washington in the summer and fall of 2008 (Table 1, Figure 1). These were primarily conducted between June and November. Timing and exact locations of these surveys were based on weather patterns and anticipated whale abundance based on sighting reports and historical data. The primary vessels employed in these dedicated photo-identification surveys were three 5.3-5.9m rigid-hull inflatables equipped with outboard engines operated by Cascadia Research and used extensively in our past photo-identification research. Vessels covered up to 200 nmi/day and operated up to 50 nmi offshore. The boats were transported from one region to another by trailer. Additional opportunities to obtain identification photographs occurred during efforts to tag and track humpback and blue whales, monitoring of marine mammals of areas in conjunction with acoustic monitoring especially off central Washington, and surveys conducted as part of collaborations with Channel Islands and Olympic Coast National Marine Sanctuaries.

A number of collaborators provided additional identification photographs obtained more opportunistically. The most extensive contribution of opportunistic photographs came from our collaboration with the Channel Islands Naturalist Corps as well as whale watch operations out of Monterey Bay and San Francisco Bay.

Table 1. Summary of effort conducted by Cascadia Research in 2008 for photo-ID.

Date	Vessel	Locality	Start Time	End Time	Total Effort (Hrs)	Distance (nm)	Objective
Surveys-California							
5/18/2008	N1	San Diego- Ensenada	8:40	16:58	8:18	120	General Photo ID
5/20/2008	N1	Ensenada-San Diego	13:30	18:48	5:18	75	General Photo ID
6/9/2008	N1	Mission Bay	7:50	17:41	9:51		Photo-ID/Tagging
6/9/2008	N2	Mission Bay	8:02	17:30	9:28	80	Bm Filming
6/10/2008	N1	Mission Bay	7:30	23:59	16:29	80	Photo-ID/Tagging
6/10/2008	N2	Mission Bay	7:42	17:40	9:58	75.2	Photo-ID/Nat Geo Filming
6/11/2008	N2	Mission Bay	10:10	17:51	7:41	84.4	Photo-ID/Nat Geo Filming
6/11/2008	N1	Mission Bay	10:30	17:45	7:15	68	Photo-ID/Tagging
6/12/2008	N2	San Diego	7:48	15:36	7:48	91.7	Photo-ID/Nat Geo Filming
6/12/2008	N1	San Diego to Ensenada	7:45	19:26	11:41	173	General Photo ID
6/13/2008	N1	San Diego into Mexico	7:50	19:30	11:40	121	Photo-ID/Tagging
6/13/2008	N2	San Diego into Mexico	7:51	19:00	11:09	79.4	Photo-ID/Nat Geo Filming
6/14/2008	N1	San Diego	8:08	18:30	10:22	63	Photo-ID/Tagging
6/14/2008	N2	San Diego	8:01	14:45	6:44	53.1	Photo-ID/Nat Geo Filming
6/15/2008	N1	Mission Bay	8:30	18:05	9:35	70	Photo-ID/Tagging
6/15/2008	N2	Mission Bay	8:40	17:21	8:41	85.3	Photo-ID/Nat Geo Filming
6/16/2008	N1	Mission Bay	8:20	16:48	8:28	75	Photo-ID/Tagging
6/17/2008	N1	San Diego to Ensenada	8:20	18:55	10:35		Photo-ID/Tagging
6/18/2008	N1	Ensenada to San Diego	9:35	16:45	7:10	91	Photo-ID/Tagging
8/14/2008	ZIP	Port San Luis	7:50	15:38	7:48	68.7	General Photo ID
8/14/2008	N2	Santa Barbara Channel	10:51	18:40	7:49		Tagging
8/15/2008	ZIP	Port San Luis	7:48	15:52	8:04	104	General Photo ID
8/15/2008	N2	Santa Barbara Channel	8:45	19:57	11:12	120	Tagging
8/16/2008	ZIP	Morro Bay	8:32	19:13	10:41	73.9	General Photo ID
8/16/2008	N2	Santa Barbara Channel	9:20	20:20	11:00	67	Tagging
8/17/2008	ZIP	Santa Barbara	9:30	19:10	8:41	83.6	Discovery Filming
8/17/2008	N2	Santa Barbara Channel	9:25	19:15	9:50	105	Tagging
8/18/2008	N2	Ventura	8:05	17:37	9:32		General Photo ID
8/18/2008	ZIP	Ventura	8:15	17:35	9:20	92.7	Bm Fliming
8/19/2008	N2	Ventura	8:15	16:10	7:55		Tagging
8/19/2008	ZIP	Ventura	8:16	16:04	7:48	77.3	Tagging
8/31/2008	N2	Long Beach	10:19	16:28	6:09	64.9	General Photo ID
9/7/2008	N2	Santa Monica Bay	13:40	19:56	6:16	79	General Photo ID
9/8/2008	N2	Santa Barbara Channel	8:40	19:40	11:00	120	Tagging
9/9/2008	N2	Santa Barbara Channel	9:12	18:30	9:18	170	Tagging
9/10/2008	N2	Santa Barbara Channel	9:40	19:00	9:20	67	Tagging
9/11/2008	N2	Santa Barbara	8:30	17:37	9:07	80	Tagging
9/12/2008	N2	Santa Barbara Channel	7:55	19:25	11:30	118	Tagging
9/13/2008	N2	Santa Barbara Channel	8:25	18:35	10:10	91	Tagging
9/14/2008	N2	Monterey Bay	9:45	14:55	5:10		General Photo ID
9/16/2008	N2	Half Moon Bay	13:55	19:15	5:20	46.5	General Photo ID
9/17/2008	N2	Bodega Bay	9:58	19:03	9:05	97.5	General Photo ID
9/18/2008	N2	Bodega Bay	9:17	18:52	9:35	96.6	General Photo ID
9/19/2008	N2	Half Moon Bay	9:38	15:34	5:56	62.2	General Photo ID
10/20/2008	ZIP	Pt St George	10:45	18:50	8:05	100	General Photo ID
10/21/2008	ZIP	Pt St George	9:20	16:00	6:40	61	General Photo ID
10/22/2008	ZIP	Bodega Bay	8:45	18:53	10:08	118	General Photo ID
10/23/2008	ZIP	Bodega/Cordell	8:45	18:40	9:55	92	General Photo ID
10/24/2008	ZIP	Pt St George	12:20	14:20	2:00	18	General Photo ID
11/2/2008	N2	Marina del Rey	8:09	15:27	7:18	69.2	General Photo ID
11/3/2008	N2	Santa Barbara Channel	9:37	12:35	2:58	36.3	General Photo ID
11/5/2008	N2	Half Moon Bay	7:05	17:04	9:59	109	General Photo ID
11/6/2008	N2	Half Moon Bay	7:20	14:36	7:16	76.3	General Photo ID
Surveys-Washigton and Oregon							
1/23/2008	ZIP	Westport	8:30	16:33	8:03	111	
3/5/2008	N1	Westport	11:15	13:35	2:20		
4/1/2008	ZIP	Westport	8:31	16:38	8:07	147	
5/29/2008	N2	Westport	7:39	18:00	11:01	134	
7/2/2008	ZIP	Westport	8:46	18:44	9:30	158	
7/5/2008	ZIP	Sekiu	18:08	22:00	3:52		Humpback entanglement
7/6/2008	ZIP	Sekiu	6:15	11:45	5:30		Humpback entanglement
7/10/2008	ZIP	Sekiu	17:30	21:45	4:15		Humpback entanglement
7/15/2008	Wind Song	Neah Bay	7:30	16:56	9:26		General Photo ID
8/10/2008	ZIP	Westport	7:50	19:40	11:20	133	
9/2/2008	ZIP	Westport	7:55	16:25	8:30	140	
10/15/2008	ZIP	Westport	8:15	16:30	8:15	105	
10/19/2008	ZIP	Depoe Bay	11:45	18:24	6:39	110	General Photo ID

Figure 1. Survey effort in 2008 including small surveys by Cascadia Research (in white) and collaborators including Channel Islands Naturalist Corps in the Santa Barbara Channel (green). Surveys off Washington include those conducted in collaboration with the Olympic Coast National Marine Sanctuary and Scripps Institution of Oceanography (funded by N45 program). SWFSC cruise tracks and effort are not included above.

Photographic identification from ship surveys

A critical part of the mark-recapture estimates for blue whales was the systematic identifications obtained in conjunction with broad-scale SWFSC marine mammal ship surveys. Key samples for the current study were the identifications obtained during the 2005 and 2008 SWFSC surveys covering waters out to 300 nmi off California, Oregon, and Washington. Additional fine-scale survey effort was completed during CSCAPE 2005 in waters of four West Coast National Marine Sanctuaries, providing additional blue whale identifications in nearshore waters.

Data analyses

All photographs were judged using a three-tier quality criterion. This score, along with associated sighting information (date, latitude, longitude), was entered into the identification database for analysis. Identification photographs of suitable quality were internally compared to identify resightings (and remove duplicates) of animals for each year. Each individual was then compared to Cascadia's historical catalog (archived photographs) of all blue whales identified off northern Baja, California, Oregon and Washington. Individual whales identified each year that did not match past years and which were of suitable quality were assigned a new unique identification number and added to the catalog annually.

Estimates of humpback and blue whale abundance were made using several capture-recapture methods (Calambokidis and Barlow 2004). The primary methods were two-sample Petersen capture-recapture estimates (Chapman modification for sampling without replacement) conducted using the identifications obtained in different pairs of samples including: 1) pairs of adjacent years as the two samples, and 2) identifications from the systematic broad-scale and fine-scale ship surveys as one sample and the second sample from the coastal surveys for the same time period. An unbiased estimate of blue whale abundance using the two-sample Petersen estimate requires that all animals in the population have an equal probability of being photographed in at least one of the samples. The second sample does not have to meet this criterion as long as it is independent of the first sample. This approach of using the identifications from the systematic ship surveys as the one representative sample provided reliable estimates of blue whale abundance for similar surveys in the past (Calambokidis and Barlow 2004).

We also conducted the first estimates of blue whale abundance using mark-recapture between feeding and wintering areas. This type of approach has been found to be the least biased method of estimating humpback whale abundance because it allows for more complete mixing of animals and avoids problems with heterogeneity of capture probability that often results from sampling biases in a particular region (Calambokidis et al. 2008, Barlow et al. submitted).

RESULTS

Overall 2008 provided relatively large number of photographic identifications of both humpback and blue whales distributed fairly widely among regions (Table 2). While these distributions partly reflected the locations of effort, they also revealed patterns of concentration of both species. For blue whales, identifications were concentrated in the southern California Bight especially off northern Baja to areas off San Diego and in the Santa Barbara Channel with only smaller numbers of sightings in other regions. For humpback whales most identifications were made off central California from Monterey Bay to Bodega Bay.

Humpback whales

For all of the US West Coast 808 identifications were made of 497 unique humpback whales (Table 2). This represented the largest number of individuals identified in any year of research so far along the US West Coast (Table 3). Identifications were obtained from February to November and ranging from Southern California to the Washington/BC border area (Table 2). Regions where larger samples were obtained (>50) included the Santa Barbara Channel area from April to June (thanks to collaborators like the Channel Islands Naturalist Corps), Morro Bay area in August, Monterey Bay area for September to November, Gulf of the Farallones to Bodega Bay in September and October, and northern Washington in June.

Table 2. Summary of identifications of humpback whales in 2008 by month and region.

Region	Code	2	3	4	5	6	7	8	9	10	11	Total	IDs
S Ca. Bight (south)	31			2								2	2
Santa Barbara Channel	33			35	76	52	4	9	4		3	183	102
S. California (offshore)	39									1		1	1
Pt Conception to Buchon	41							13				13	13
Pt Buchon to Pt. Sur	42							87				87	74
C. California offshore	49									4		4	4
S Monterey Bay Sanc.	51		2		15				33	115	98	263	128
N Monterey Bay Sanc.	52								6		12	18	18
Farallones/Cordell	53								88	59	8	155	131
C Mend. to Klamath Riv.	62									2		2	2
C. Oregon	72							2				2	2
N Oregon	73							3				3	3
Washington	75				2	4	1	4				11	11
Wash/BC border	76					52	7			2		61	47
WA/BC inside waters	79	2				1						3	2
Total		2	2	37	93	109	12	118	131	183	121	808	497
Unique IDs		1	2	26	63	89	8	99	115	115	71	497	

Identifications in 2008 were obtained from many of the same areas that have been sampled in past years. The record number of unique IDs in 2008 was not the result of unusually high numbers of identifications in any one area but the good returns at many areas. For all years, 2,257 unique humpback whales have been identified off the US West Coast through 2008 (Table 3).

Table 3. Number of identifications of humpback whales by year and region through 2008. Totals by year and region also show number of unique IDs excluding resightings.

Region	Code	<1986	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total	IDs
S Ca. Bight (south)	31							5		5	3			4					3		5				2	23	21
S. Ca. Bight (north outside S	32				1		1		3	1	7	29			5			9	1				9			66	45
Santa Barbara Channel	33				5		14	28	222	11	21	259	33	42	169	22	1	3	104	83	35	204	130	193	183	1762	471
S. California (offshore)	39																					2		5	1	12	12
Pt Conception to Buchon	41			8	115			169	4	1	23	32		29	3	2	133	25	44	14	49	51			13	715	287
Pt Buchon to Pt. Sur	42				2		2	26					8	18	16	9	5	4			23	117	13		87	330	216
C. California offshore	49																								4	4	4
S Monterey Bay Sanc.	51	3		6	18	2	13	38	101	86	83	58	158	133	283	358	424	137	70	171	145	219	254	18	263	3041	834
N Monterey Bay Sanc.	52				2		30			33	4	55	97	53	43	14		192	43	83	89	25	12	9	18	802	461
Farallones/Cordell	53	18	466	794	401	267	316	181	372	336	261	216	250	37	150	148	43	101	156	141	89	42	46	170	155	5156	1073
Bodega Bay to Pt. Arena	54		1		5				119	8			5	5	41	2				5			2			193	113
Pt. Arena to C. Mendocino	61							5	116	2				25	27				22	10		5				212	152
C Mend. to Klamath Riv.	62	1			11			4		4		13	8	28	6						8	34	34	11	2	164	137
N California to Oregon	63				3			212	68	25		1		16	112	9		3	9	24	8	39	2	15		546	241
S Oregon	71								2									5	2							9	9
C. Oregon	72						23						7			49	9	2	35	1		6			2	134	99
N Oregon	73								14									1		1				1	3	20	12
Washington	75						5								1			6			7	39	9	15	11	93	85
Wash/BC border	76				1	1	10	14		3	18	50	55	24	70	102	56	53	41	10	45	43		29	61	686	275
Puget Sound	79				3						2			2							8	4	1		3	23	14
Total		22	467	808	567	270	414	682	1021	515	422	713	621	416	926	715	671	541	530	543	511	830	512	466	808	13991	
Unique IDs		19	91	150	212	110	217	282	397	256	260	363	366	291	433	385	268	306	345	396	329	443	302	332	497		2257

The data from 2008 was used to generate updated mark-recapture estimates of humpback whale abundance for two separate regions: 1) California and Oregon and 2) Washington. For the primary area of California and Oregon, 438 unique individuals were identified off California and Oregon, the highest number obtained in any of effort to date (Table 4). An additional 59 animals were identified off Washington but are used in a separate abundance estimates since these potentially represent a different feeding area (Calambokidis et al. 1996, 2001, 2004, 2008).

Petersen mark-recapture estimates for California-Oregon yielded estimates for 2007-2008 of 2,043 humpback whales, the largest we have obtained to date. While the overall rate of increase since 1991 has generally been around 8% and not unreasonable, the trend just for the last 10 years has both been more erratic and after an apparent drop after 1998 more rapid (Figure 2). Several factors appear to be at work. Even though the population has increased, our sample size each year has remained fairly constant; this has resulted in lower numbers of recaptures between years (lower recapture rates reflect higher abundance estimates) and higher CVs which are largely driven by numbers of recaptures. As the proportion of the population sampled has decreased and resulted in lower recapture rates, the potential influence of biasing factors to the abundance estimates has increased.

Table 4. Summary of identifications in pairs of adjacent years (n1 and n2) and matches (m) off California and Oregon along with Petersen mark-recapture estimates of abundance and CV.

Year	n1	n2	m	Pop	CV
1990-91	206	269	105	**526**	0.05
1991-92	269	397	188	**568**	0.03
1992-93	397	253	173	**580**	0.03
1993-94	253	244	108	**570**	0.05
1994-95	244	329	100	**799**	0.06
1995-96	329	332	146	**747**	0.05
1996-97	332	268	106	**836**	0.06
1997-98	268	386	120	**859**	0.06
1998-99	386	329	129	**981**	0.06
1999-2000	329	228	108	**692**	0.06
2000-01	228	266	81	**745**	0.07
2001-02	266	313	85	**974**	0.08
2002-03	313	386	92	**1,306**	0.08
2003-04	386	280	79	**1,358**	0.08
2004-05	280	366	67	**1,516**	0.09
2005-06	366	292	88	**1,207**	0.08
2006-07	292	297	54	**1,587**	0.11
2007-08	297	438	63	**2,043**	0.10

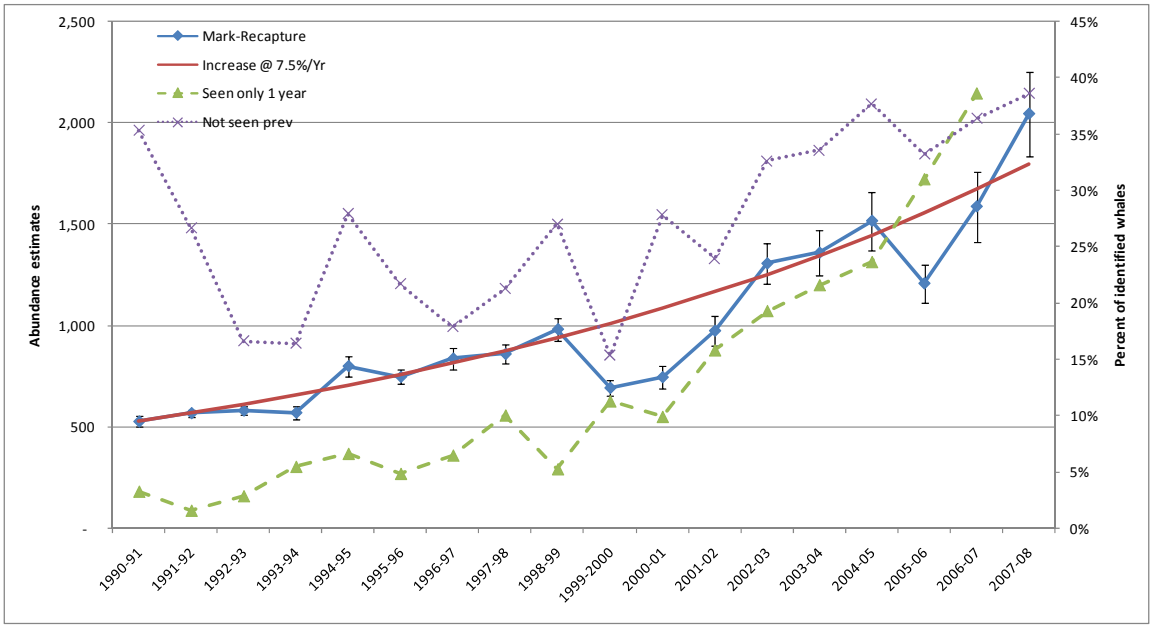

Figure 2. Abundance estimates of humpback whales from mark-recapture off California and Oregon through 2008 based on Petersen mark-recapture estimates using adjacent years as samples. Left axis also shows proportion of identified animals not seen previously and the proportion seen only one year. Error bars show ± 1 SE.

Abundance estimates for Washington were more constrained by sample size (Figure 3). Some consecutive years had to be pooled into a single sample for there to be an adequate number of recaptures between pairs of years in the Petersen mark-recapture estimates. Despite this limitation, these estimates indicated an increase in abundance from the mid 1990s when initial identifications were made and recent years. Confidence limits were much tighter in the 1990s reflecting a larger number of recaptures between samples than in recent years when even with pooling years, the low recapture rate resulted in not only higher estimates of abundance but a great deal of uncertainty around the estimates. One change that may be biasing these results is that through the mid-2000s, photo-IDs came from a more limited area corresponding to the area close to the border between Washington and British Columbia and more recently we have also been conducting surveys off central Washington almost year around resulting in expanded coverage. Earlier estimates may have been biased downward due to heterogeneity of capture probabilities from this geographic sampling bias.

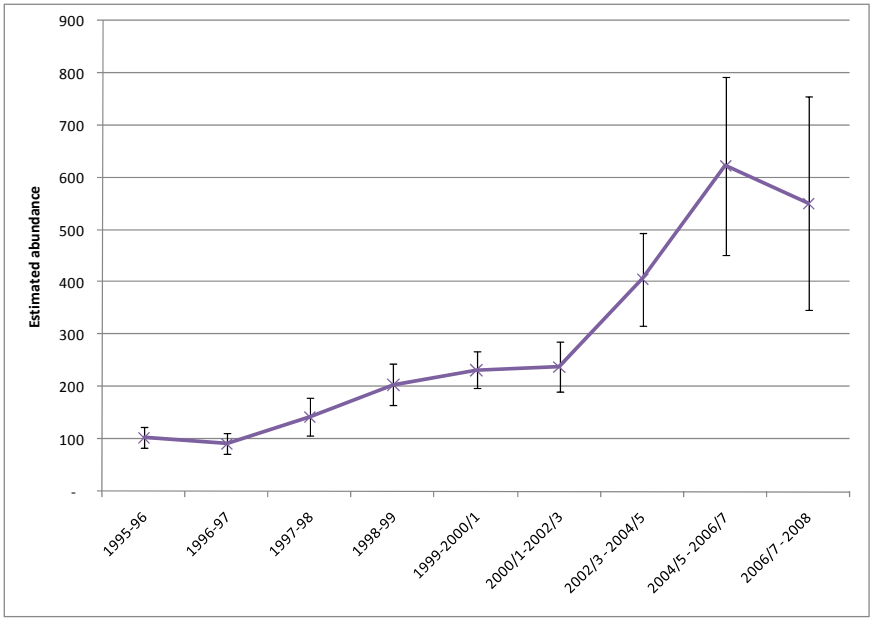

Figure 3. Abundance estimates of humpback whales from mark-recapture off Washington through 2008 based on Petersen mark-recapture estimates using adjacent years as samples. In case were there were six or less recaptures between samples, adjacent years were pooled to increase sample size for comparison as indicated. Error bars show ± 1 SE.

One possibility considered was whether any of the high rates of increase in abundance in the last 10 years could be the result of immigration from other areas. This might be expected especially if humpback whale abundances in different regions reach carrying capacity at different times and thereby prompting movement of animals among regions beyond what had been occurring. There was no indication of this movement in the SPLASH inter-regional matches which showed very low rates of interchange between California-Oregon and other feeding areas (Calambokidis et al. 2008). Additionally, we examined the distribution of mtDNA haplotypes by latitude for evidence of animals coming from other areas. Past studies showed a dramatic difference in mtDNA haplotypes between humpback whales that feed off California, dominated by E and F2 haplotypes, and those from SE Alaska which are primarily A- and A+ haplotypes

(Baker et al. 1990, 1994, 1998). Much more extensive analyses conducted in recent years especially the SPLASH years of 2004 to 2006 reveal a dramatic latitudinal gradient in the proportions of these haplotypes and still very few animals off California with the haplotype patterns that dominate Northern British Columbia and SE Alaska (Figure 4).

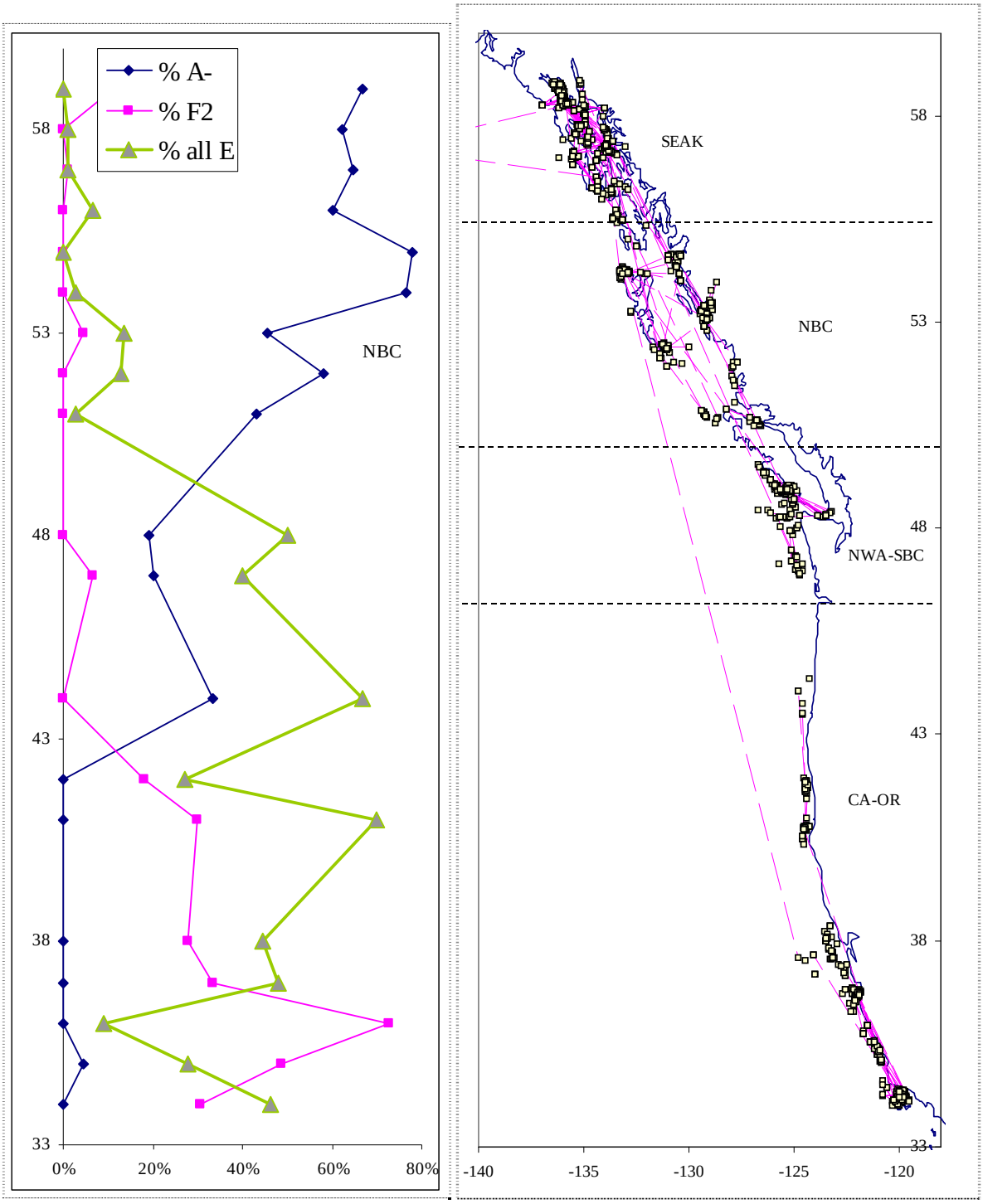

Figure 4. Humpback whale mtDNA haplotype proportions by latitude from California to SE Alaska (data from Baker et al.1990, 1998, unpublished data).

Blue whales

A total of 437 identifications of 216 unique blue whales were made along the West Coast from the west coast of Baja to Washington. Almost half of these came from the Santa Barbara Channel although this was from a broad period stretching from June to December (Table 5). Smaller samples were obtained off S California (mostly off San Diego) and the west coast of northern Baja down to just south of Ensenada mostly from June to August. Blue whales were also identified from the Gulf of the Farallones to Bodega mostly in September and October.

Table 5. Identifications of blue whales by month and region in 2008. Numbers show number of acceptable identifications including resightings, totals by month and region also show number of unique IDs excluding duplicate sightings.

Region	Code	5	6	7	8	9	10	11	12	Total	IDs
N Baja	24	1	42		1					44	29
S Ca. Bight (south)	31		25	10	23	4				62	43
S. Ca. Bight (north excl SBC)	32			2	5	40				47	21
Santa Barbara Channel	33		1	51	75	79	23	3	4	236	106
S. California (offshore)	39				3		2	2		7	7
Farallones/Cordell	53					14	13	2		29	27
C. California offshore	59						1			1	1
Pt. Arena to C. Mendocino	61					2				2	2
Offshore N Californria	69				2	3				5	5
S Oregon	71				2					2	2
N Oregon	73				2					2	2
Total		1	68	63	113	142	39	7	4	437	216
Unique IDs		1	40	48	69	72	27	7	4	216	

While 2008 represented a fairly typical year for obtaining blue whale identifications it was well below the record 353 different blue whales identified in 2007 when large concentrations occurred both off San Diego early in the summer and in the Santa Barbara Channel in late summer and fall (Table 6). In 2007 these record numbers of blue whales in the Santa Barbara Channel coincided with a high rate of ship strikes of blue whales with at least four killed in fall 2007. With 2008, the catalog of unique blue whales from the US west coast now numbers 2,052.

Table 6. Identifications of blue whales by year and region in 2008. Numbers show number of acceptable identifications including resightings, totals by year and region also show number of unique IDs excluding duplicate sightings.

Region	Code	<1986	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total	IDs
N Baja	24	4		1	52	42		2	1	4		7			4	9	12			6		3	84		44	275	192
S Ca. Bight (south)	31	3						23	1	9	1	42	17	11	86		13	119	9	20	4	1	325	142	62	887	421
S. Ca. Bight (north excl SBC)	32		2				5	1	19	6	36	139	12	29	1			282	54	28	6		4		47	671	365
Santa Barbara Channel	33								253		307	165	150	190	126	297	22	21	316	28	184	157	28	796	236	3276	963
S. California (offshore)	39	3	1					20		40			9						2			14	1		7	97	87
Pt Conception to Buchon	41							4		2	9	6	2	8			34	6	48	42		2				163	117
Pt Buchon to Pt. Sur	42									2			7			8	3	15				10				45	39
S Monterey Bay Sanc.	51	11	73	79	39	19			7	22	30	11	36	13	103	16	183	74	43	283	18	59				1119	512
N Monterey Bay Sanc.	52	3					2		1	90		3	8	4	16	6		27	4	13	2	10				189	118
Farallones/Cordell	53	7	83	136	167	123	240	55	181	30	49	7	49	56	37	82	84	23	54	111	25	10	2	22	29	1662	525
Bodega Bay to Pt. Arena	54				20	1	2		33		1		5	7	4	5			6				1			85	57
C. California offshore	59							3		13			2												1	19	15
Pt. Arena to C. Mendocino	61							2	175					4	9			2	1			8			2	203	111
C Mend. to Klamath Riv.	62														7							25	9	1		42	28
N California to Oregon	63							4	4						14			2		10	29	7	2	1		73	49
Offshore N Californria	69																								5	5	5
S Oregon	71																	1				6	1		2	10	9
C. Oregon	72																	1								1	1
N Oregon	73																					2			2	4	4
British Columbia	82													1						2		2	1	8		14	10
Total		31	159	216	278	185	249	114	675	218	433	380	297	323	407	423	351	573	537	543	268	316	458	970	437	8841	2052
Unique IDs		28	82	128	149	115	108	77	281	129	211	232	183	180	231	182	184	284	307	296	189	182	234	358	216	2052	

Estimates of blue whales were generated for 2005 to 2008 (Table 7). It was not possible to estimate blue whale abundance from the 2008 systematic surveys alone because of the small sample size obtained in those surveys (15 left side images and 10 right sides). This was due primarily to the relatively low rate of blue whale sightings in the 2008 survey (Barlow 2009).

Blue whale photographic identifications from 2008 including those from systematic surveys were used to improve the most recent abundance estimates that had been based on data through 2006 (including the 2005 CSCAPE surveys) (Calambokidis et al. 2007). The 2005 to 2008 period allowed pooling both the 2005 CSCAPE and 2008 SWFSC surveys for the systematic surveys and the 2005-2008 period for the comparison sample from all other effort (Table 7). This pooled sample yielded a slightly lower estimate (2,497 versus 2,842) with a tighter CV and was more in line with the past estimates than the one based on just IDs from the 2005 CSCAPE surveys (Calambokidis et al 2007). The most recent estimates were still higher than those from 1991 to 2002, suggesting a possible increase in abundance in recent years.

Table 7. Blue whale abundance estimates incorporating the 2008 identifications

Samples	**Left sides**					**Right sides**					**Mean**
	n1	**n2**	**m**	**Est.**	**CV1**	**n1**	**n2**	**m**	**Est.**	**CV1**	
Past estimates											
1991-93	61	293	8	**2,024**	0.29	74	289	10	**1,976**	0.26	**2,000**
1995-97	43	350	7	**1,930**	0.30	34	361	7	**1,583**	0.29	**1,756**
2000-2002	20	452	5	**1,585**	0.32	24	474	5	**1,978**	0.33	**1,781**
2004-2006	35	352	5	**2,117**	0.34	38	365	3	**3,568**	0.42	**2,842**
New estimates using 2005 to 2008											
2005-2008 All Qual	50	548	9	**2,799**	0.27	47	548	11	**2,195**	0.24	**2,497**
2005-2008 Gd Qual Non-Syst	50	264	4	**2,702**	0.38	47	246	4	**2,370**	0.38	**2,536**
2005-2008 Gd Qual Syst	39	548	7	**2,744**	0.30	37	548	6	**2,979**	0.32	**2,862**
2005-2008 only Gd Qual	39	264	3	**2,649**	0.42	37	246	3	**2,346**	0.42	**2,497**

This larger sample size also allowed alternate estimates to be made based only on higher quality photo-IDs to test whether the poorer quality IDs were biasing the estimate by creating missed matches. While estimates using only the higher quality IDs were more variable due to the smaller sample size they were in the same range as the estimates using all photographs indicating there did not appear to be a bias using all photographs (Table 7).

Blue whale identifications from 2008 allowed estimates of overall blue whale abundance from mark-recapture estimates using identifications on wintering areas compared to identifications on summer feeding areas. An expedition to the Costa Rica Dome in January 2008 conducted by Cascadia Research, Oregon State University, and Scripps and sponsored by National Geographic obtained identifications of 65 blue whales on the Costa Rica Dome (Cascadia Research unpublished data). Suction cup tag deployments and observations revealed this area was being used as a feeding area (as well as a winter calving and mating area). Mark-recapture estimates based on one sample from the 2008 Dome expedition and the other sample from West Coast identification in summer and fall 2007 and 2008 yielded much higher abundance estimates than those obtained comparing feeding area samples (Table 8). These results are also higher than those based on identifications from a previous fall/winter expeditions to the Dome in 1999-2000 which yielded estimates much closer to those obtained with the

feeding area samples. The high estimates based on the 2008 sample suggests the Dome is used by some blue whales that do not feed off California and the abundance estimate using the Dome is not just for the portion of the population that feeds off the US West Coast.

Table 8. Estimates of blue whale abundance based on Petersen mark-recapture estimates using one sample from the Fall/winter near the Costa Rica Dome and another sample from summer/fall feeding areas off West Baja and California.

Samples	Left sides					Right sides					Mean
	n1	n2	m	Est.	CV1	n1	n2	m	Est.	CV1	
2008 Dome - 2007-2008 West Coast	57	401	2	**7,771**	0.49	62	383	5	**4,031**	0.36	**5,901**
1998-2001 Dome vs West Coast	20	521	3	**2,740**	0.40	20	508	3	**2,671**	0.40	**2,705**

In order to examine trends in abundance of blue whales with larger more consistent samples we conducted inter-year Petersen mark-recapture estimates based on adjacent years samples since 1992 similar to what was conducted with humpback whales (Figure 5). These abundance estimates while useful for examining trends in abundance underestimate true abundance because of heterogeneity of capture probabilities from the coastal bias of these samples making some animals more likely to be consistently recaptured. These estimates do indicate a significant upward trend in abundance of blue whales (linear regression, r^2=.035, p=0.012) although at a rate of under 3% per year. This increase could also be partly or entirely the result of shifts in other factors that might alter the degree of bias in these estimates. Blue whales appear to have shifted aspects of their distribution in the eastern North Pacific in the last 10 years (Calambokidis et al. 2009) and this has resulted in changes in estimated densities of blue whales from line-transect surveys (Barlow 2009, Barlow and Forney 2007, Forney 2007).

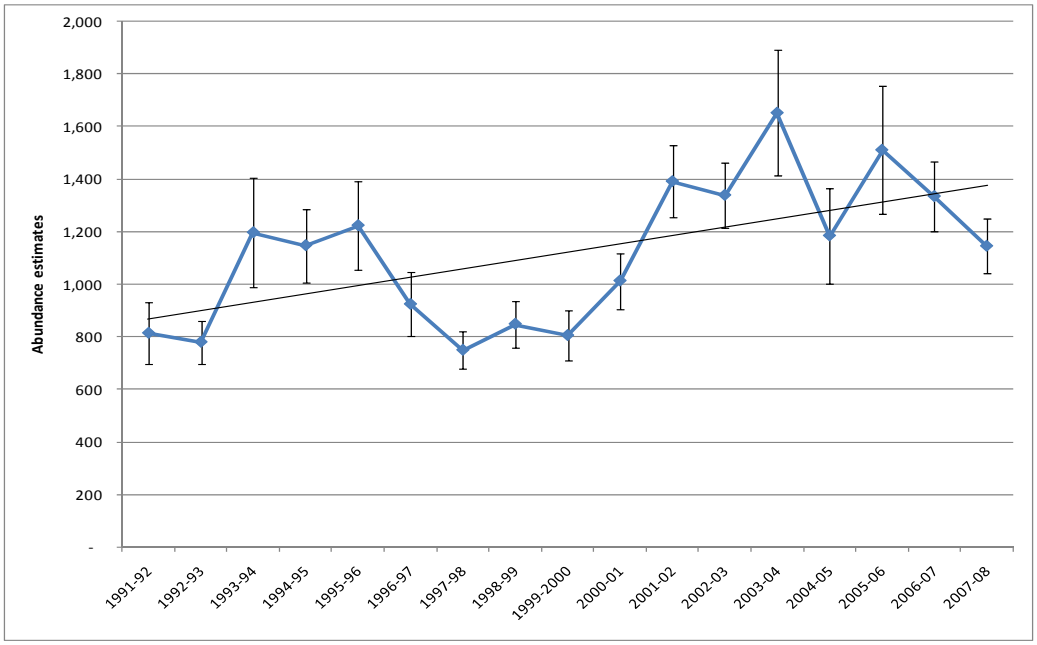

Figure 5. Estimates of blue whale abundance based on Petersen mark-recapture estimates of photographically identified individuals in adjacent years for west Baja to Washington. Error bars show ± 1 SE.

The abundance estimates of blue whales from mark-recapture are very different from those from density estimates based on line transect ship surveys (Forney 2007, Barlow 2009). While these two estimates of abundance showed good agreement with estimates of about 2,000 animals in the 1990s (Calambokidis and Barlow 2004), they now have diverged (Figure 6) with the line-transect estimates for the last three surveys all yielding abundance estimates of under 1,000 with the most recent estimate of 508 for 2008 (Barlow 2009). These methods measure different things and the agreement in the 1990s suggested that most of the population was present in the survey area during the line-transect surveys (Calambokidis and Barlow 2004) and the divergence in recent years appears to be the result of blue whales having shifted to a broader geographic distribution including into areas off British Columbia and in the Gulf of Alaska where they were common during commercial whaling (Calambokidis et al. 2009).

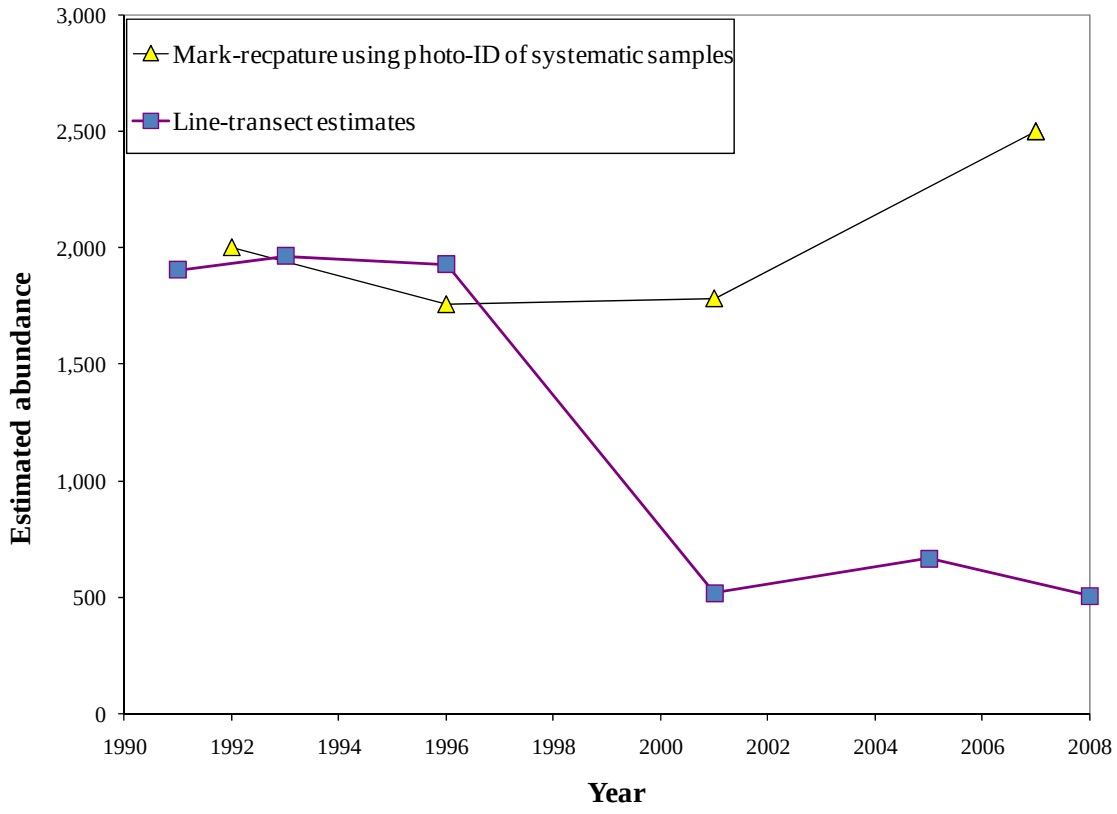

Figure 6. Comparison of blue whale abundance estimates from mark-recapture (including this study) and line transect from SWFSC cruises (Barlow and Forney 2007, Forney 2007, Barlow 2009).

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